

Observatory Improvements for SOFIA

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The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a joint project between NASA and Deutsches Zentrum für Luft- und Raumfahrt (DLR), the German Space Agency. SOFIA is based in a Boeing 747 SP and flown in the stratosphere to observe infrared wavelengths unobservable from the ground. In 2007 Dryden Flight Research Center (DFRC) inherited and began work on improving the plane and its telescope. The improvements continue today with upgrading the plane and improving the telescope. The Observatory Verification and Validation (V&V) process is to ensure that the observatory is where the program says it is. The Telescope Status Display (TSD) will provide any information from the on board network to monitors that will display the requested information. In order to assess risks to the program, one must work through the various threats associated with that risk. Once all the risks are closed the program can work towards improving the observatory.

Nomenclature

ARC= Ames Research Center
DAOF=Dryden Aircraft Operations Facility
DFRC= Dryden Flight Research Center
DLR= Deutsches Zentrum für Luft- und Raumfahrt
FORCAST= Faint Object Infrared Camera for the SOFIA Telescope
GUI= Graphical User Interface
L3= L3 Communications
MCCS= Mission Controls and Communications System
NASA= National Aeronautics and Space Administration
SCAI=
SOFIA= Stratospheric Observatory for Infrared Astronomy
TA= Telescope Assembly
TSD= Telescope Status Display
USRA= Universities Space Research Association
USRP= Undergraduate Student Research Program
V&V= Verification and Validation

I. Introduction

During the summer of 2011, Robert Peralta attended Dryden Flight Research Center (DFRC) for an Undergraduate Student Research Program (USRP) session. The goal for the summer was to assist mentor Steve Jensen with various engineering projects and bring them to the observatory level. The following details the objectives of my internship and the document overview.

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A. Objectives:

1. Assist various SCAI team members with the observatory V&V process.
2. Create a situational awareness display for the cabin of the 747 SP.
3. Help mitigate program risk #22

B. Document Overview:

This document is organized as follows: first will be background information about SOFIA and the main arguments for why the program is unique. Then information about the tasks I worked on this summer, the results from those tasks lessons learned and where to go from the current status.

II. Background

A. General Background

The thought process, meaning the idea of SOFIA and how to carry out its mission's, has been around for over twenty years. SOFIA was originally going to be operated out of NASA's Ames Research Center (ARC) with science teams from the Universities Space Research Association (USRA), one of NASA's science contractors. When the program began to slip behind schedule, NASA almost terminated the program but Dryden Flight Research Center (DFRC) was able to gain the contract. The plane was taken to a hanger, owned by L3 Communications (L3), in Waco, Texas. While in the hanger the Telescope Assembly (TA) Cavity, the cavity in the fuselage where the telescope is located, was made. The telescope then arrived from Germany and an "air scope"* was added to prevent any turbulent air flow inside the TA Cavity. Once the plane was retrofitted, it was flown to the Dryden Aircraft Operations Facility (DAOF) in 2007, where the plane is currently housed. On May 26th 2010, SOFIA flew the Faint Object Infrared Camera for the SOFIA Telescope (FORCAST) instrument and captured its "First Light"[†] thus starting its time as a working observatory. Although still in development, SOFIA continues to collect science.

B. Arguments for SOFIA

SOFIA is a flying observatory, and as such, can perform many tasks in the infrared spectrum that is out of reach of ground based infrared observatories. The infrared wavelength is almost unobtainable from Earth because the wavelength is scattered by the water vapor in Earth's atmosphere. However, SOFIA can fly above 99% of that water vapor thus giving it a much better view into the infrared universe. Of course the best place for an infrared observatory is in space, but with that comes many complications, such as: cyro-coolers running out, making the telescope warm and ineffective for infrared science, and out dated instrumentation. SOFIA can use cyro-coolers and be able to replace them with ease once they run out; when newer infrared technology is available, newer instruments can be brought on board making SOFIA able to adapt to the latest and greatest technology. Ground based observatories are just that, ground based; if there is an event that won't pass over an observatory, the science from that event could be lost. SOFIA, being a plane based observatory, can travel almost anywhere in the world to collect science.

III. Tasks

A. Observatory V&V

With the observatory now operational, the program and science teams need to know how well the telescope can collect science. The program has tasked the Observatory V&V team with verifying that the telescope meets the requirements set by DLR, NASA, and the science community in which SOFIA serves. The V&V team then needs to validate how we know we've verified the requirements. The main benefit of the V&V process is to be able to present an observatory that can deliver what the program says it can, in terms of science capabilities. The outcome of this process is to identify any requirements that have yet to be met, that way the V&V team knows where to focus their efforts. However, if it turns out that all requirements have been met, then the V&V team and the program knows not to focus on the requirements and would then begin working on improving the systems that need to be

* A mechanism inside the TA Cavity designed to keep the laminar air flow moving across the telescopes field of view.

† The first time a science mission and science data was collected.

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updated. The V&V process is important for any engineering project and no observatory can collect good science if the optics isn't up to the required standards.

Many of the requirements of SOFIA involve image quality, meaning how well the telescope can “see”. One of the first things the SCAI team needed to do was to understand what was involved with the image quality. Image quality is defined as the contributing factors to the “seeing” of the telescope. Fortunately, during my previous internship with SOFIA, with help from Dr. Eric Becklin, I was able to come up with an image quality budget that broke down the “seeing” of the telescope into its contributing factors and gave an amount of error that each factor contributed to the overall image quality. From there I was able to look at the values of the image quality budget that Dr. Becklin and I came up with and check them against the requirements to see if the telescope is performing where the program says it is.

However, with the complicity program, having changed NASA centers and the fact that the program involves two aerospace organizations; the requirements have been changed, forgotten or waived in the process. Currently there are at least three different requirement documents: SOF_1011, SOF_1069 and the PCA*. The problem of multiple, different, requirements documents is determining with requirement document to follow. Luckily, there was one requirement document that is treated as the all-inclusive document. Since the requirements could have changed as the program aged, a requirement trace was needed. The requirement trace entailed following the image quality requirements from the original requirement document, down through the requirements given to the program from NASA headquarters, to the current requirement document.

B. Telescope Status Display (TSD)

During a flight, the mission director has access to all incoming information from the plane's network, which includes the telescope, the science and support team's data, and other observer data. The mission director is in charge of this because the science team and other support staff are too busy with conducting the experiments and have to focus on that information. With this information flow configuration the problem of needing said information arises. As the information flow is now, the mission director has access to all the network information and people must request the information from the mission director. This process of asking and answering takes away from the mission director's job, which is to ensure that the mission goes smoothly and good science is collected. The TSD will make needed formation more readily available to whoever will need it, thus leaving the mission director able to focus on other tasks.

Since the TSD is going to display information from various network systems, the science teams will be able to access the information they need. A display is only useful if it displays the information that is needed. To solve that problem, I thought it would be best to ask them what they would consider to be helpful that they would want to see on the display. From the responses I got back, I then made a list of all of the requests that were the same and then some that I thought would be useful. I then worked on drawing up what the displays might look like on the monitors and then filled in the information that was requested. All of the requested information could fit into two or three categories: Flight, Telescope, and Cavity. The user will retrieve the needed data via a touch screen Graphical User Interface (GUI). Below is what the proposed GUI will look like.

*The Program level requirements dictated by NASA headquarters

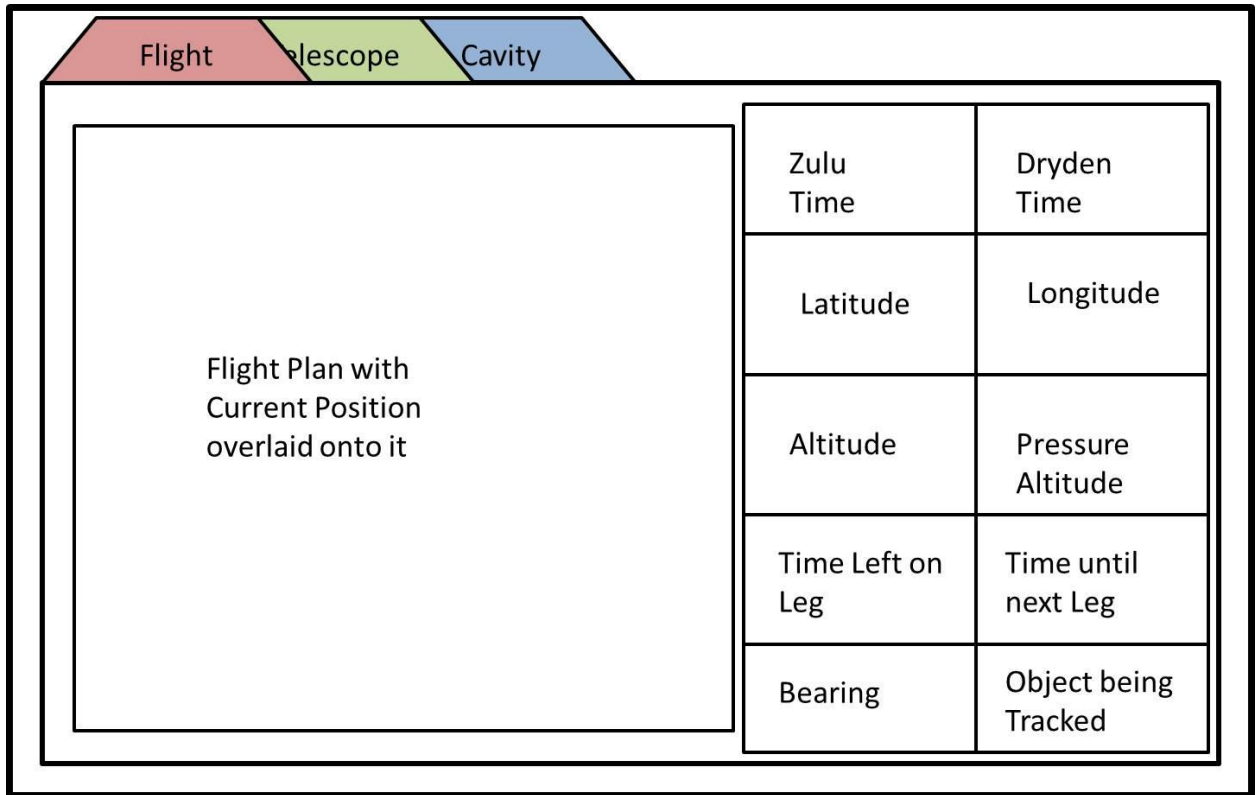


Figure 1. Flight data tab.

The latitude, longitude, altitude and pressure altitude are used for positioning and to understand how the “seeing” is affected by the shear layer. The time on leg and time left on leg is used for time keeping in terms of observing an object.

| Flight | Telescope | Cavity | | | | | | | | |
|---|-------------------|--------|-----------|-------------|-------------------|-------------------|---------------|----------------|--------------|-------------------|
| <table><tr><td>Zulu time</td><td>Dryden Time</td></tr><tr><td>Chopper Amplitude</td><td>Chopper Frequency</td></tr><tr><td>Chopper Angle</td><td>Chopper Offset</td></tr><tr><td>Focus Number</td><td>Imager being used</td></tr></table> | | | Zulu time | Dryden Time | Chopper Amplitude | Chopper Frequency | Chopper Angle | Chopper Offset | Focus Number | Imager being used |
| Zulu time | Dryden Time | | | | | | | | | |
| Chopper Amplitude | Chopper Frequency | | | | | | | | | |
| Chopper Angle | Chopper Offset | | | | | | | | | |
| Focus Number | Imager being used | | | | | | | | | |

Figure 2. Telescope data tab.

The telescope SOFIA uses is similar to a reflecting telescope, meaning the light comes in and gets reflected from the primary mirror to the secondary mirror and then gets reflected again to the tertiary mirror and enters the instrument. Chopping is when the telescope is looking at an object and the secondary mirror “moves” to another position so the telescope is then looking at background noise; the secondary mirror then moves back into position on the object. This process is done so when analyzing the data the scientist can subtract just the background signal from the background plus object signal, thus leaving them with just the signal of the object. The chopper needs to be watched because it can chop too much, thus rendering the data useless to the scientist.

| Flight | Telescope | Cavity | | | | | | | | |
|--|-------------|--------|-----------|-------------|---------------|-----------|-------------|----------|------------------|----------|
| <table><tr><td>Zulu Time</td><td>Dryden Time</td></tr><tr><td>Water Vapor %</td><td>Dew Point</td></tr><tr><td>Cavity Temp</td><td>PMA Temp</td></tr><tr><td>Tracker Position</td><td>Tracking</td></tr></table> | | | Zulu Time | Dryden Time | Water Vapor % | Dew Point | Cavity Temp | PMA Temp | Tracker Position | Tracking |
| Zulu Time | Dryden Time | | | | | | | | | |
| Water Vapor % | Dew Point | | | | | | | | | |
| Cavity Temp | PMA Temp | | | | | | | | | |
| Tracker Position | Tracking | | | | | | | | | |

Figure 3. Cavity data tab.

The mirrors of the telescope are very sensitive to moisture; therefore, it is important to know the cavity temperature and the present of water vapor in the cavity. With those two values, dew point can be calculated. The temperature of the primary and secondary mirrors can greatly affect the focus number, which needs to be precise in order to get good science. This configuration will require many small sized touch screen monitors placed around the science equipment to reduce crowding around one screen. It will also make the information much easier to read than if it was all on one monitor.

C. Risk

With every engineering project comes with risks to either the science platform or the project itself. The key to a successful project is to anticipate these risks and mitigate them. For SOFIA, every risk is assigned various threats. These threats act as broken down components of the risks to make it easier to mitigate their assigned risk. If SOFIA is to be successful as an observatory and as a science platform then these threats need to be mitigated in order for the risks to be closed. Each threat and risk is assigned a value of how likely it is that the threat will happen and a value for the impact if the consequence of that threat happens. Each threat is then assigned to a person, who then works to mitigate that threat. Once all the threats are mitigated the risk can be closed.

I was assigned program risk number 22, which has to do with long term support from science community. The underlying tone of risk is to keep the costs of SOFIA from outweighing the benefits that SOFIA offers the science community. Many of the objects of interest for those interested in infrared astronomy, like the Galactic Center, can only be viewed from the Southern Hemisphere. One of threats of risk 22 deals with exactly this issue. One of the best arguments for SOFIA is that it can be deployed anywhere around the world to collect science and SOFIA has yet to go beyond the equator.

IV. Conclusion

A. Results

Many of the image quality requirements were verified to be correct or within reasonable tolerance and will need to be improved at a later date. The values that did not meet the requirements will be looked at further to see if they just need to be validated or if the contributing factor needs to be improved. I have submitted my designs to the engineers who will then create a GUI and then show that to the scientists and others who will be using the TSD to get their input and to make any changes. Afterwards, the monitors will be put into place and the GUI's will be coded in and the information will be available to anyone who needs it. Although none of threats were closed work towards closing them has progressed. Now that these threats are being worked on, more associated threats can be added to risk #22 if any arise.

B. Lessons Learned

From my work with the Observatory V&V team, I learned that organization is crucial to running research program, such as SOFIA, and to a successful research experiment. If I ever become a principal investigator, I now realize that it is more than just thinking of experiments and then carrying them out, it takes much more precise planning and I feel like I understand how to better plan out an experiment now. From my work with the TSD, I learned that asking the intended audience what they would like to see, helped me understand how important communication is, especially for a program like SOFIA. From working on risks, I have learned to plan for problems before the happen that way I can correct them before they become a problem. I have heard about that many times during my schooling but now I feel like I have learned it.

V. Next Steps

Due to the fact that there are multiple requirement documents, work will begin on complying them into one requirements document that will then act as the benchmark. During that process the V&V work will continue and will adapt once the single requirement documents is formed. If my proposed plan for the TSD is implemented, various monitors will need to be bought, and installed onto the plane. After that a subsystem will probably need to be created to get the information from the MCCS network to the monitors. More work is still needed to close all the threats; which will close the risk. Working on identifying associated threats will need to be done to make sure that we capture and mitigate as many threats as possible.

VI. Acknowledgements

I would like to thank the following people for their invaluable assistance during my 2011 USRP internship session: Steve Jenson, Walt Miller, Jana Killbrew, Marty Hench, James Milsk, Eric Becklin, Matt Enga, and Scott Miller.

VII. References

¹ Miller, S, "SOFIA_Risk_22," NASA Ames Research Center, Moffett Field, CA, 2008.

² Miller, W, "SOF_1011," SOF_library, NASA Ames Research Center, Moffett Field, CA, 2008.